Stanford Energy Behavior Initiative

Carrie Armel
Precourt Energy Efficiency Center, Stanford

EE Actions or "Behaviors"

1. Purchase and install EE technology
   - Purchase EE versions of new items; replace or improve existing items if they are malfunctioning or inefficient (extra insulation for hot water heater, etc.)
2. Reduce waste
   - Unplug extra fridge, extra TiVo, icemaker, pottery wheel, etc.
3. Shift settings and install controls
   - Adjust fridge temperature, pool pump cycles, thermostat/AC; add timers and controllers on devices
4. Repair items or perform maintenance
   - Repair malfunctioning or inefficient items; clean filters, etc.
5. Adjust patterns of use and habits
   - Close drapes and windows on hot days; shut off lights & TV, etc.

Our goal is to reduce EE Actions or Behaviors. People often think that I mean habits, like shutting off the lights, when I say this. I'd like to clarify that our project addresses several types of actions or behaviors, not just habits, including …[slide bullets]

It might be worth noting that we focus on residential buildings, and some light commercial

We are creating a human-centered system that leverages pervasive sensor and communication technologies to achieve large-scale energy savings

Advanced Research Projects Agency – Energy (ARPA-E)

- **Cost-Sharing from CEC and Stanford**

Interdisciplinary

- 15 faculty
- 10 departments, 5 schools, 5 centers
- 30+ students
- **Faculty Director: Professor Byron Reeves**
- **Project Director: Carrie Armel**

Human Sciences and Technologies Advanced Research Institute | Precourt Energy Efficiency Center | Design for Change Lab | CIFE Center for Integrated Facility Engineering | Stanford Prevention Research Center

Our funding is from the relatively new federal agency – arpa-e at doe, which is modeled off of darpa, but focuses on energy. Our initiative has ~20 different projects. Our team includes 15 faculty from 10 departments ranging from…CS, EE, CEE, Econ, on the one hand, and Psych, Comm, Education, Behavioral Epidemiology at the School of Medicine on the other.

The projects all center around how to leverage smart meter or other sensor data, with behavioral techniques, to maximize energy savings.

The **Problems**

1. **Billions** for **"smart"** infrastructure
   - Smart meters, home area networks, transportation and other sensors
2. **Energy efficiency** is **difficult**
   - Figuring out what to do and how to do it is difficult and boring

How can we address both of these issues? How can we leverage smart infrastructure to maximize energy savings?

Our initiative attempts to address the following problems.

First, billions are being spent to produce a smart infrastructure, with all of the CA IOU territory having smart meters in the next year, and an estimated half the US by 2020, yet the energy savings potential of this infrastructure – without careful consideration of the human element – will not reach its full potential.

Second, EE is difficult: Figuring out what to do and how to do it is difficult and boring

How can we address both of these issues? How can we leverage smart infrastructure to maximize energy savings?

The **Solution**

Quantification!

1. **Provide diagnostics / personalized recommendations**
2. **Increase motivation through specialized behavioral techniques**
   - Feedback
   - Incentives
   - Markets
   - Competitions
   - Data visualization
3. **Create the best programs** with unprecedented speed, ease, cost, and scale – via objective evaluation of program energy savings

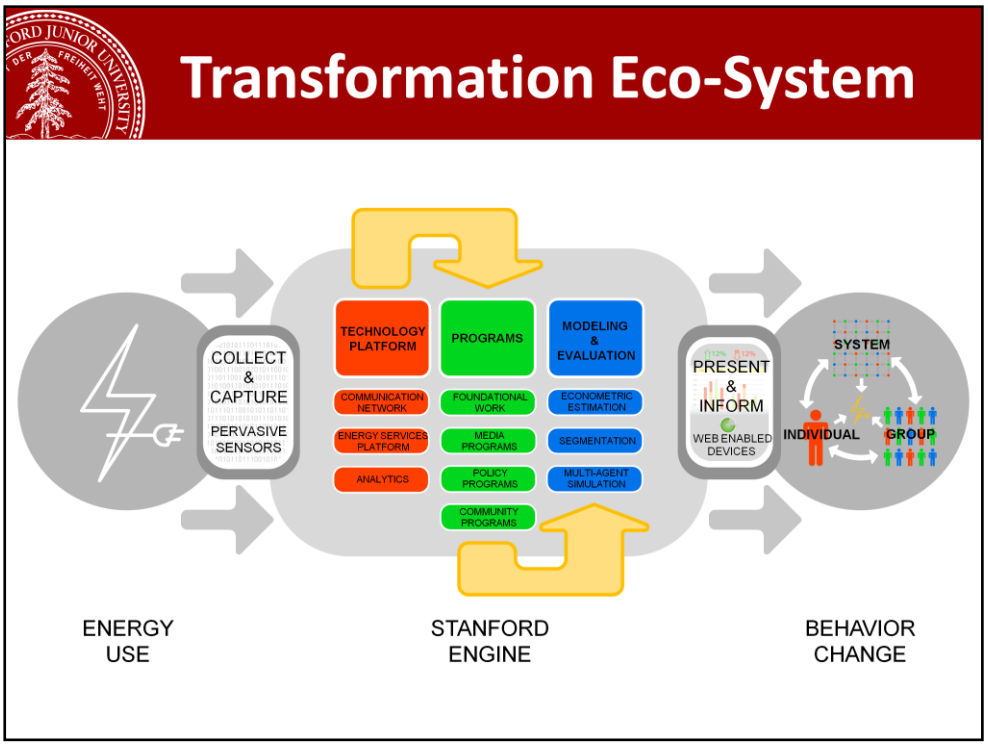
Our solution is that a smart infrastructure enables quantification, which in turn enables ways to reduce energy use.

For one, it enables diagnostics or personalized recommendations, so that people aren't left guessing what they should do. [Once they know what to do, we can use other approaches to simplify how to do it.]

Second, quantification enables a variety of behavioral techniques that were difficult to implement before. For example, Feedback, Incentives, Markets, Competitions, Data visualization. [These increase motivation.]

Third, quantification allows us to create the best programs with unprecedented speed, ease, cost, and scale – through objective evaluation of program energy savings.

Let's look at how to achieve these things with a smart infrastructure.



Here's an overview of our project.

We are at a unique point in history, and have a great opportunity on our hands because:

- Wireless sensors (e.g., Smart meters, HAN, Gas, transportation, hot water sensors) are becoming pervasive, enabling quantification of energy information

- And web enabled devices are Pervasive - so that computers and phones can deliver programs to help individuals reduce energy use

We ask: How can we leverage smart infrastructure to achieve deep and widespread energy savings?

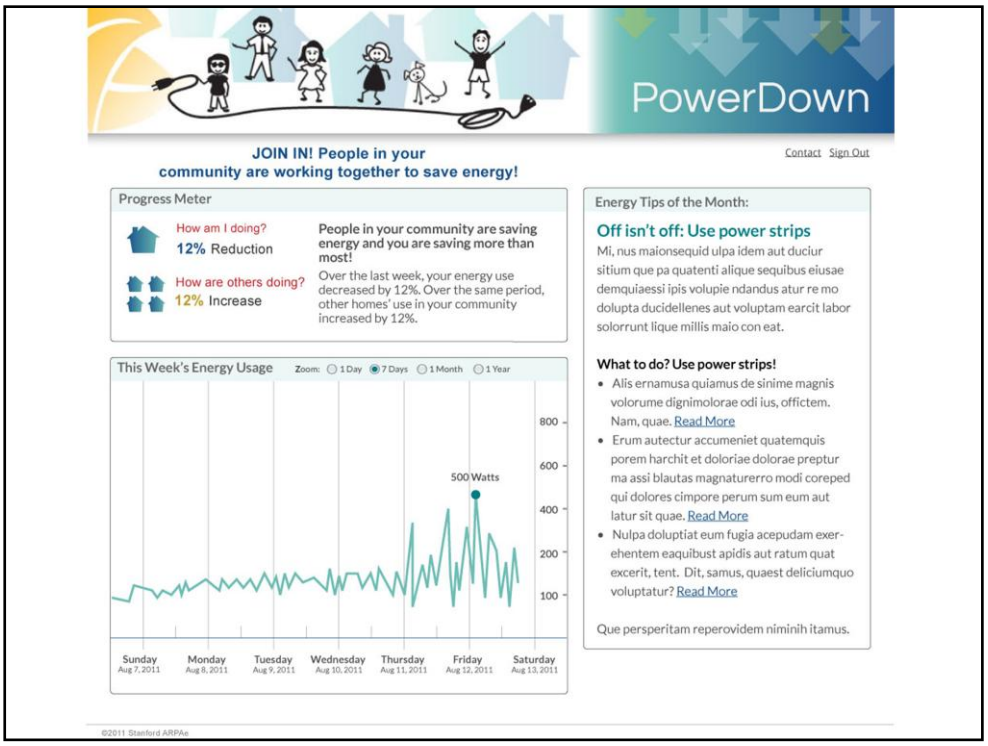
To address this, in the middle, we have Stanford's Engine which links the pervasive sensors and web-enabled devices.

The engine includes 3 buckets – each which uses quantification of sensor data in a different way.

1. The first bucket is the technology platform, and includes projects that use sensor data to perform analytics - like diagnostics on where a given individual should save energy through disaggregation. The tech platform also supports data capture and storage, and includes some comm protocol dev't work.
2. The second bucket includes our programs or interventions – these live on top of the tech platform. Here, quantification enables a variety of behavioral techniques to be used that were difficult to use previously. For example, Feedback, Incentives, Markets, Competitions, Data visualization. ~~[These increase motivation.]~~
3. The third bucket includes modeling and evaluation. Here, quantification allows us quantify program savings and inform policy. Quantification also enables us to create the best programs with speed, ease, cost, and scale – because we can objectively evaluate their energy savings and refine programs accordingly.

Thus, the projects all center around how to leverage smart meter or other sensor data, with behavioral techniques, to maximize energy savings.

This is a landing page from which we can get to 5 of the 7 intervention projects, from that middle bucket I just described. I'll talk about a few of these now.



This is our simple feedback interface - The data is graphed, compared to one's baseline in the past, compared to one's neighbors energy use, and the user is also given recommendations, and sent emails at strategic times.

All of our projects are set up so that we can easily change the features displayed, and track their effectiveness in reducing energy on customers. This project in particular looks at the impact of how we organize recommendations, and also the impact of using message framing about one's community versus individual action.

All of the projects I'll discuss also use web collector technology – so that we can get utility smart meter data into the programs. That is, a homeowner simply provides their online utility username and password – so the homeowner opts in, and direct interfacing with the utilities is not necessary. This is standard technology that is used in Mint.com for financial information, EarthAid.net, etc.

In addition to utility data, we can take in data from other sensors, like TED devices, home area networks, etc.

Greg Walton

Prof Byron Reeves project is PowerHouse, an online game that incorporates real world energy data into some of the game play. For example, on the graph page presented here one can challenge their friends to a “lights out night” etc and then see who won based on the actual data. The game play in this background game trains people up in a short amount of time to turn off appliances when not in use, by providing points or reinforcement in a sped up timeframe.

Some eye-opening facts about games:

The audience of this genre is big, with as many as 400M people worldwide that operate avatars in virtual environments (Gartner, 2007).

It is also surprisingly diverse, given that gamers average 33 years old (there are more of them in their 40’s or 50’s than in their teens), the majority of them have full time jobs and kids, and the gender ratio ranges from equal to 3:1 depending on the genre.

Furthermore, people are coming to expect engagement in workplace settings as well – IBM and other corporations are beginning to incorporate game-like elements and virtual meetings into work tasks.

This game has been evaluated in a laboratory setting, in which individuals turn off more electronics in the room when leaving if they’ve played the game. In a study where individuals played the game in their homes over 10 weeks, it also seemed to reduce energy use slightly during that period.

ChangeLabs

PI: Banny Banerjee
Scale: FaceBook

Kidogo

PowerTower

Prof Banny Banerjee's group has created three FB Apps. Kidogo allows one to compute their real world energy savings, and then microfinance individuals in developing countries based on their savings. A premise behind this is that the monetary savings that Americans get from reducing energy is relatively small, so that microfinancing stretches the value of one's money.

PowerTower on the right is a tetras-like energy saving game. Individuals get blocks based on how much energy they've saved. You can also create a team and compete with other teams – building your blocks into a tower to see who can get the highest.

These apps are in process of being tested on FB.

Prof Balaji Prabhakar has another incentive program, that also aims to stretch the value of monetary savings. Here, participants get credits that correspond to cash for shifting to off-peak travel, or for mode shifting (from private to public transit~~), or for recommending a friend~~. Then individuals can choose to participate in a simple game of chance – that looks a bit like chutes & ladders in the upper right corner - to win a shot at a larger amount of money. Individuals are poor at assessing probability and also erroneously sense that their strategy can influence outcomes, and are very engaged in trying to win these larger sums of money.

INSINC was launched in January 2012 in Singapore, and in 6months exceeded their goal of 20k users (21,000).

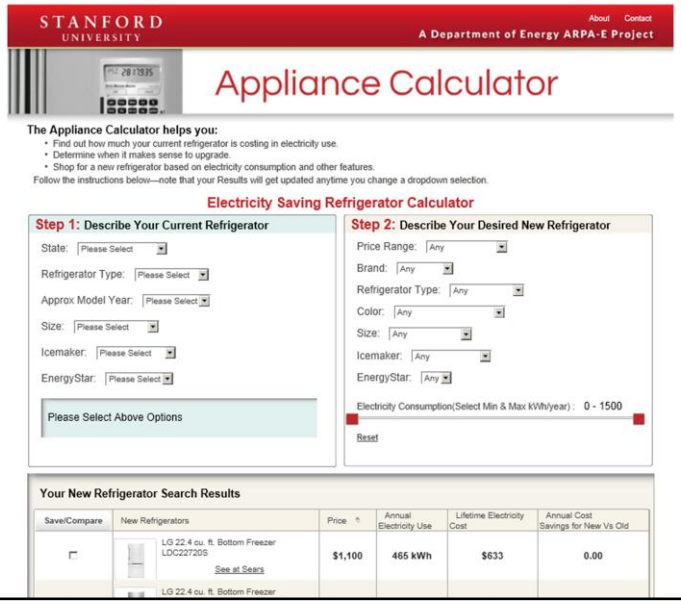
A $p < 0.05$ level of significance was observed for utilization of public transit and shifting time of use in the optimal direction. 11-12 percent of users in Singapore shifted off-peak

~~Balaji has also expanded this work to stanford campus and in non-transport domains: step/health, recycling. It's been difficult for him to line up a home energy program.~~

Balaji Prabhakar

Energy Calc.

PI: Sam McClure
Scale: Google AdWords



Prof Sam McClure's Appliance Calculator application allows folks to compare their current appliance's consumption to any new appliance on the market in terms of energy costs that meet their desired attributes compares to the energy use and cost of their existing appliance on energy consumption and other factors – and then click through to buy the new appliance.

We've run 4 experiments to date, testing different ways of framing information, e.g., by using behavioral economic nudges. More than 60,000 online shoppers have come to this study through Google Ads. The basic findings, which are intriguing, suggest that projecting out cost savings over time does not have an impact on click-throughs, whereas simply changing the sort order to put the most efficient appliances on top does.

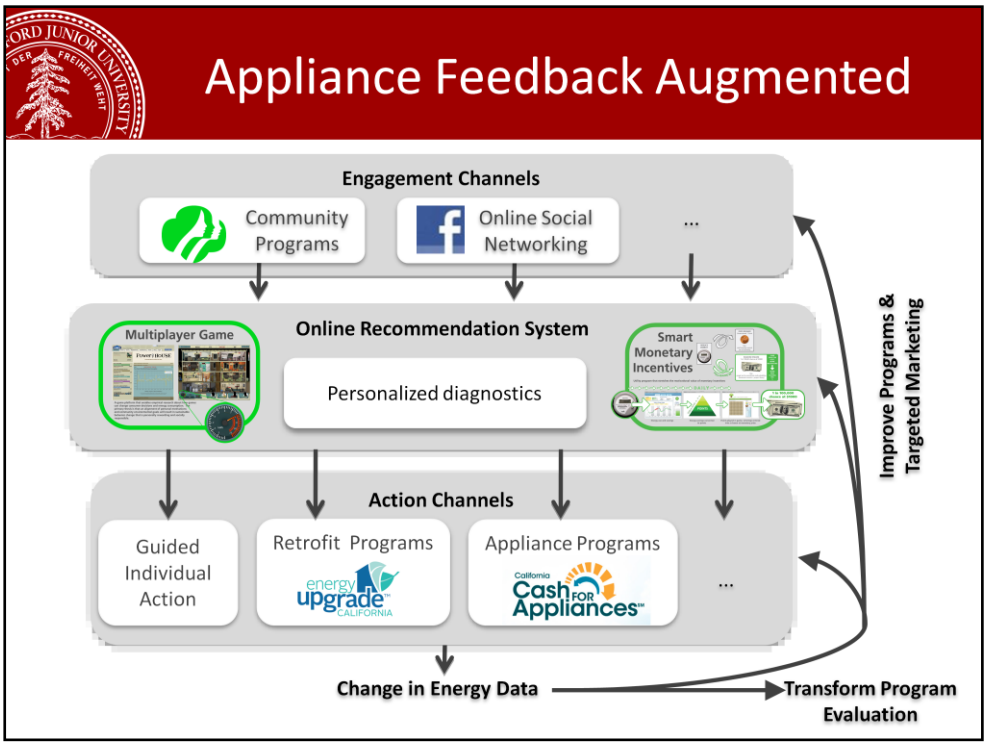
Profs Tom Robinson and Nicole Ardoin lead our community girl scout program. The girl scouts have high penetration – one in two women in the U.S. have been a girl scout, and how many people here have bought girl scout cookies in the last few years? Typically a raise of hands shows ~30-100% of folks.

Here you see a screen shot of the landing page for the website for the program. On the right you can see the badges we designed for our program.

We tested the 5 session program in 30 troops – half of the troops focused on reducing home energy use, and the other half on transport and food energy use.

Throughout the program, to draw families to the website to make deeper energy savings, the girls act as reporters and create a video telling others how to reduce energy…then their families can then view the videos online on the website – which draws them to the website.

----Preliminary results indicate significant changes in reported energy-saving behaviors by children in both interventions, with stronger effects in the home energy curriculum group.

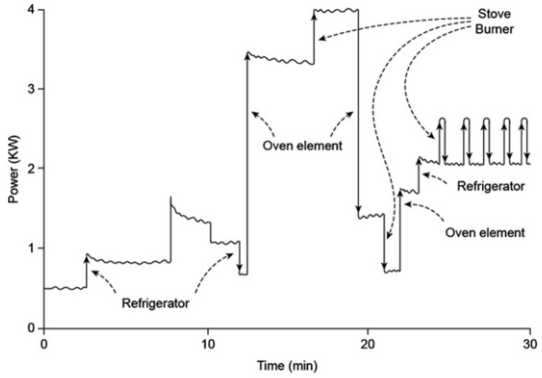


For the most part, the projects have been pursued independently to date. To tie things together for you, this diagram illustrates one way they might be integrated.

1. At the top we have engagement channels. We know from other efforts that only ~0-4% of utility customers etc. actually go to an energy website that the utilities advertise. On the other hand, environmental community based programs sometimes get as high as ~85% participation in communities. Thus, we see community programs like the Girl Scouts, and online social networking sites like FaceBook, at the top, playing a strategic role in channeling folks to
2. A web based recommendation system, which provides diagnostics about whether you in particular should get a retrofit, replace specific appliances because they are inefficient or malfunctioning, etc. (I'll describe that a bit more in a second),
3. And these diagnostics allow us to channel you into specific programs and incentives that makes it easier to take action
4. Motivation can be increased to revisit this system for more recommendations, through novel incentives or media that make specific use of the data (e.g., some of what I showed you today)
5. Changes in energy use data are then used to evaluate and improve the programs, improve targeted marketing, and improve program evaluation for utility credits.

Energy Disaggregation

Disaggregation allows us to take a whole building (aggregate) energy signal, and separate it into appliance specific data (i.e., plug or end use data). A set of statistical approaches are applied to accomplish this.



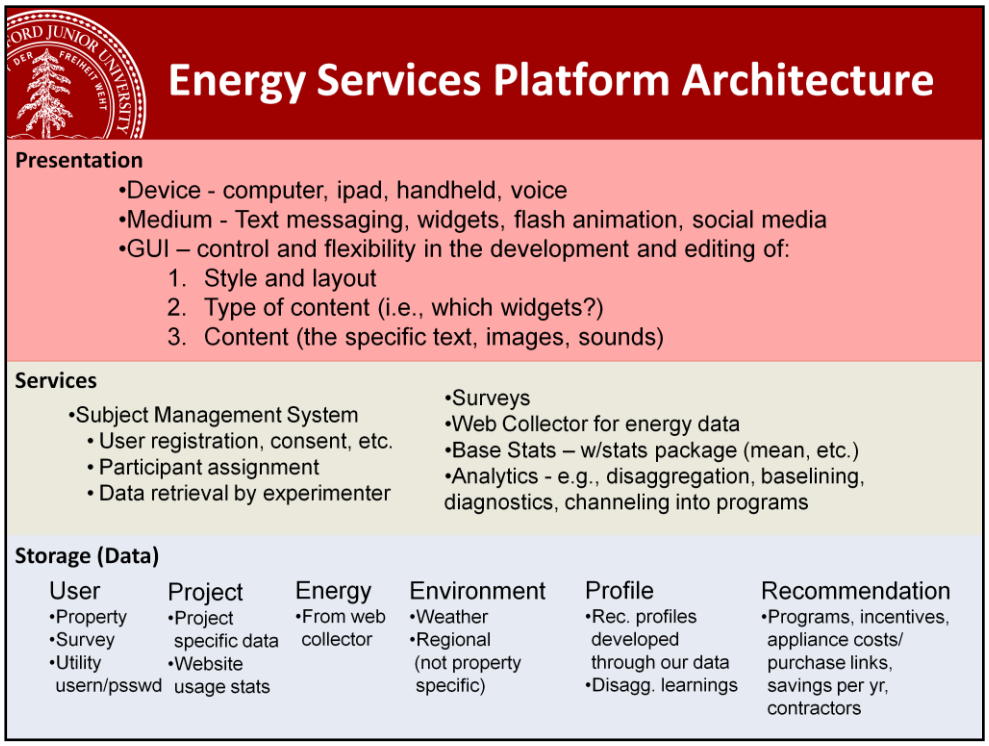
One final note – a key piece of this model is to be able to perform diagnostics and recommendations automatically and at scale. We think that Energy Disaggregation using smart meter data could achieve this.

Disaggregation allows us to take a whole building (aggregate) energy signal, and separate it into appliance specific data (i.e., plug-level or end-use data). A set of statistical approaches are applied to accomplish this.

There are often around 100 end uses of energy in a home so that it is hard for individuals to determine what they should do to save energy, and studies show that there is 200-300% differences in energy use between identical housing units due to appliance saturation and lifestyle patterns. So there's a fair amount of variability in what people should be doing to reduce their energy use that warrants diagnostics.

Current meters can accomplish disaggregation for approximately 10 end uses, once the Home Area Network is activated, and improved future deployments of meters could do more.

Andrew Ng, Zico Kolter



We developed an Energy Services Platform to support these and future projects, which we are in process of making available to others.

This can be organized into three layers:

1. The presentation layer, which is what the user sees, and includes the device, the medium (like website or text messaging), and the GUI (including the content, style and layout). And we've built this out to be flexible so that we can display across platforms and build in different ways.
2. The services layer is anything that require computation, logic, or analytics, like subject assignment, etc. [Many of the screens corresponding to this I actually didn't show today, in the interest of time.]
3. And the Storage layer contains all of the data.

Stanford ARPA-E Team

Principal Investigator
Byron Reeves

Project Director
Carrie Armel

Core Investigators
Banny Banerjee, Tom Robinson, Jim Sweeney, June Flora

Investigators
Hamid Aghajan, Nicole Ardoin, Martin Fischer, Abby King, Phil Levis, Sam McClure, Andrew Ng, Ram Rajagopal, Balaji Prabhakar, Jeff Shrager, Greg Walton, John Weyant

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Graduate Students
Adrian Albert, Matt Crowley, James Cummings, David Gar, Sebastien Houde, Amir Kavousian, Maria Kazandjieva, Amir Khalili, Deepak Merugu, Ansu Sahoo, James Scarborough, Anant Sudarshan, David Paunesku, Scott White

Publications

Conference and Journal Publications To Date

- **Stanford ARPAe Energy and Behavior Initiative: Publications and Peer-reviewed presentations**
- **Project 2A: PEEC Staff: Carrie Armel**
- Flora, J. A., Boudet, H., Armel, K.C., & Roumpani, M. (In preparation). A Behavior Change Attribute Model: The Case of Residential Energy Behavior.
- Cornelius, M., Armel, C. & Ardoin, N. (2011). *Identifying the Most Promising Options for Residential Energy Savings*. Presented at the Behavior Energy and Climate Change Conference
- Roumpani, M, Flora, J., Boudet, H., & Armel, C. (2011) *Behavior Attributes of Residential Energy Reduction Actions*. Presented at the Behavior Energy and Climate Change Conference
- **Project 2B: PEEC Staff: Carrie Armel**
- Armel, K. C., Gupta, A., Shrimali, G., & Albert, A. (2013). Is disaggregation the holy grail of energy efficiency? The case of electricity. Energy Policy, 52, 213–234.
- Houde, S. Sudarshan, A., Todd, A. Armel, C. & Flora, J.A. (2013) Real-Time Feedback and Electricity Consumption: A Field Experiment Assessing the Potential for Savings and Persistence. The Energy Journal, 34, 1.
- Houde, S., Todd, A., Sudarshan, A., Flora, J., & Armel, C. (2010). *Appliance-specific electricity feedback: Implications for energy conservation programs and policies*. Presented at Behavior Energy and Climate Change Conference.
- Sudarshan, A., Houde, S., Todd, A., Flora, J., & Armel, C. (2010). *Energy and the Environment: Conventional and Unconventional Solutions.* Presented at 29th USAEE/IAEE North American Conference, Canada.
- ***Houde, S., Sudarshan, A., Todd, A., Armel, K.C., Flora, J.A. (2010). A Randomized Controled Trial to Evaluate the Power of Information.*** Presented at Behavior Energy and Climate Change Conference.
- ***Project 2 C: Faculty: Jeremy Bailensen***
- ***Bailey, J. Bailenson, J.N., Flora, J., Armel, K.C., Voeker, D., & Reeves, B. (submitted) . The Impact of Vivid Messages on Energy Saving Behaviors.***

Publications

- **Project 2 C: Faculty: Banny Banerjee**
- Flora, J., Voelker, D. & Banerjee, B (in preparation). Motivational Framing of Energy Reduction Applications: Impact on Self-Efficacy and Behavioral Intention.
- Banerjee, B., Flora, J.A., & Sahloo, A. (November, 2012) *Design for Change in Behavior: Technology based Interactive Software for Energy Reduction using a Transdisciplinary Process*. Presented at Behavior Energy and Climate Change Conference.
- Flora, J., Sahoo, A., Liptsey-Rahe, A., Scalamnini, A., Wong, B., Stehly, S., and Banerjee, S. (accepted May, 2012). *Engaging the Human in the Design of Residential Energy Reduction Applications*. Presented at Human Computer Interaction & Interactivity Design Workshop, Denver, CO.
- Sahoo, A., Flora, J. A., & Banerjee, B. (2011). *Behavioral Economics Implications for Online Energy Interface Designs: Pilot Studies* . Presented at the Behavior Energy and Climate Change Conference
- **Project 2 D: Media X staff: Martha Russell**
- Russell, M., Flora, J.A. Strohmaier, M., Poschko, J., Perez, J. Yu, J., Smith, M.A., Rubens, N. (2012). Semantic Analysis of Energy-Related Conversations in Social Media: A Twitter Case Study. to appear in L.Kahle and E.G. Attay, Eds., Communicating Sustainability for the Green Economy, M.E. Sharp, Armonk, NY. (Forthcoming).
- Russell, M., Flora, J., Strohmeir, M., Poschko, J., Perez, R, and Rubens, N. (2011). *Semantic analysis of energy-related conversations in social media: A twitter case study*. Presented at Persuasive Technology Conference.
- Russell, M. (2010). *Social Media Conversations and Value Networks in the Green Tech Industry*. Presentated at Behavior Energy & Climate Change Conference, Sacramento, CA.

Publications

- **Project 4: Faculty and Principal Investigator: Byron Reeves**
- Reeves, B., Cummings, J.J., Scarborough, J.K., & Yeykelis L. (2012). Increasing Energy Efficient Behaviors with a Social Game. (Under review).
- Reeves, B., Cummings, J.J., Scarborough, J.K., Flora, J., & Anderson, D. (November, 2012). *Can Games Change Energy Behavior and Reduce Consumption?* Presented at Behavior, Energy & Climate Change Conference, Sacramento, CA.
- Reeves, B., Cummings, J.J., Scarborough, J.K., Anderson, D., & Flora, J. (2012, May). *Leveraging the Engagement of Games to Change Energy Behavior*. Presented at 2012 International Conference on Collaboration Technologies and Systems, Denver, CO.
- Reeves, B., Cummings, J.J., & Anderson, D. (2011, May). *Leveraging the Engagement of Games to Change Energy Behavior*. Presented at ACM CHI Conference on Human Factors in Computing Systems, Vancouver, British Columbia.
- Reeves, B., Cummings, J. and Anderson, D. (2011) *Leveraging the engagement of games.* Presented to 2011 ACM CHI conference on Human Factors in computing systems.
- **Project 6A Faculty: Hamid Aghajan**
- Khalili, A.H., Wu, C., and Aghajan, H. (2011). "Towards adaptive and user-centric smart home applications" in *Behavior Monitoring and Interpretation*. Part of the Ambient Intelligence and Smart Environments book series (IOS Press).
- Khalili, A., Wu, C., & Aghajan, H. (March, 2010). *Hierarchical Preference Learning for Light Control from user Feedback*. Paper presented at CVPR (Computer Vision and Pattern Recognition).
- Chen, C., Aztiria, A., and Aghajan, H. (2011). *Learning Human Behaviour Patterns in Work Environments.* Presented at Workshop on CVPR4BH, in conjunction with CVPR 2011, June, 2011.
- Chen, C., Cilla, R., Wu, C, and Aghajan, H. (March, 2011). *Discovering Social Interactions in Real Work Environments.* Presented at IEEE Int. Workshop on Social Behavior Analysis, in conjunction with FG 2011.
- Chen, C. and Aghajan, H. (2011). *Multiview Social Behavior Analysis in Work Environments*. Presented at Int. Conf. on Distributed Smart Cameras (ICDSC).

Publications

- **Project 6B: Stanford Faculty: Andrew Ng; Carnegie Mellon Faculty: Zico Kolter**
- Kolter, J.Z., and Johnson, M.J.. *REDD: A public data set for energy disaggregation research*. In proceedings of the SustKDD workshop on Data Mining Applications in Sustainability, 2011
- Chadwick, S., Plano, L. Armel, C., Kolter, J. & Flora, J.A. (November, 2012). *Motivational Interviewing and Energy Feedback: Development of the Energy Reduction Motivational Interview.* Presented at Behavior Energy and Climate Change Conference (Sacramento, CA).
- Kolter, J., Chadwick, S., Plano, L., Armel, C., & Flora, J.A. (November, 2012). *Protocol for Developing High Resolution Energy Disaggregation: The Reference Energy Disaggregation Data* (REDD). Presented at Behavior Energy and Climate Change Conference (Sacramento, CA).
- **Project 9: Stanford Faculty: Tom Robinson; Oregon State Faculty: Hilary Boudet**
- Boudet, H.S., Ardoin, N. M., Flora, J. A., Armel, K.C., & Robinson, T. N. (in preparation) The role of intrapersonal, interpersonal and contextual factors in the residential, transport, and food-related energy behaviors of Girls Scouts and their families.
- Boudet, H.S., Flora, J., Ardoin, N.M., Armel, K.C., Robinson, T.C. (2012). *Changing behavior to combat climate change: The Girl Scouts Girls Learning Environment and Energy (GLEE) Program*. American Collegiate Schools of Planning Conference (Salt Lake City; UT); Behavior, Energy and Climate Change Conference (Washington, DC); Association of Environmental Studies and Sciences Conference (Santa Clara, CA); and International Association for Society and Natural Resources Conference (Edmonton, Alberta, Canada).
- Ardoin, N.M., H.S. Boudet, K. Khalil and K. O'Connor (2011). *Girls Learning Environment and Energy (GLEE): Randomized controlled-trial testing of energy efficiency curriculum.* Presented at North American Association for Environmental Education Research Symposium (Raleigh, NC).

Publications

- **Project 10: Faculty: Martin Fischer & Ram Rajagopal**
- Kavousain, A. & Rajogopal, R. (2012). *Data-Driven Benchmarking of Building Energy Efficiency Utilizing Statistical Frontier Models*. Invited paper submitted to the ASCE Journal of Computing in Civil Engineering, Special Issue on Computational Approaches to Understand and Reduce Energy Consumption in the Built Environment.
- Kavousian, A., Rajagopal, R., and Fisher, M. (2012, under review). A Method to Analze Residential Electricity Consumption Data to Inform Energy Efficiacy Programming.
- Kavousin, A. Rajagopal, R. & Fischer, M. (2013, under review). Determinants of Residential Electricity Consumption: Using Smart Meter Data to Examine the Effect of Climate, Building Characteristics, Appliance Stock, and Occupants' Behavior.
- Albert, A., Rajagopal, R. (2012, under review). Understanding Variability and Predictability in Energy Consumption Data.
- Albert, A., Rajagopal, R. (2012, under review). Customer Segmentation by Patterns in Consumption.
- Kavousian, A., Rajagopal, R., and Fisher, M. (2011). *Multivariate approachers to predicting residential electricity consumption*. Presented at the Behavior, Energy and Climate Change Conference.
- **Project 12: Faculty: Phil Levis**
- Kazandjieva, M., Heller, B., Gnawali, O., Levis, P., Kozyrakis, C. (2012). *Green Enterprise Computing Data: Assumptions and Realities*. In Proceedings of the Third International Green Computing Conference (IGCC 2012).
- JeongGil Ko (Johns Hopkins University), Joakim Eriksson and Nicolas Tsiftes (SICS), Stephen Dawson-Haggerty (UC Berkeley), Jean-Philippe Vasseur and Mathilde Durvy (Cisco Systems), Andreas Terzis (Johns Hopkins University), Adam Dunkels (SICS), and David Culler (UC Berkeley).Industry: Beyond Interoperability - Pushing the Performance of Sensor Network IP Stacks
- Jeonggil Ko, Stephen Dawson-Haggerty, Omprakash Gnawali, David Culler and Andreas Terzis. Evaluating the Performance of RPL and 6LoWPAN in TinyOS.
- Levis, P., Kazandjieva, M. (2010). *Identifying Energy Waste through Dense Power Sensing and Utilization Monitoring.* Presented at The 8th ACM Conference on Embedded Networked Sensor Systems (SenSys 2010) in Zurich, Switzerland. http://sensys.acm.org/2010/index.html

Publications

- Jeonggil Ko, Joakim Eriksson, Nicolas Tsiftes, Stephen Dawson-Haggerty, Andreas Terzis, Adam Dunkels and David Culler. ContikiRPL and TinyRPL: Happy Together.
- Kazandjieva, M., Gnawali, O. & Levis, P. (November, 2010). *Demo abstract: Visualizing sensor network data with Powertron.* Presented at The 8th ACM Conference on Embedded Networked Sensor Systems (SenSys 2010) in Zurich, Switzerland. http://sensys.acm.org/2010/index.html
- Kazandjieva, M., Heller, B., Levis, P., & Kozyrakis, C. (2009) *Energy dumpster diving*. In workshop Power Aware Computing and System (Hot Power, 09).